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GEORGE C. MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

LUNAR FLIGHT STUDY SERIES. VOLUME 1

EARTH-MOON TRANSIT STUDIES BASED ON EPHEMERIS DATA
AND USING BEST AVAILABLE COMPUTER PROGRAM.

PART I: PERISELENUM CONDITIONS AS FUNCTION
OF INJECTION CONDITIONS

By

Byrd Tucker

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BYRD TUCKER

ABSTRACT 11809

Based on ephemeris data between 1964 and 1969, free flights from earth to moon are investigated by representative examples as to the relationships between injection conditions and periselenum conditions. Emphasis is placed on injection conditions that are compatible with due east launch from Atlantic Missile Range by means of Saturn class vehicles.

AUTHOR

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FUTURE PROJECTS BRANCH
AEROBALLISTICS DIVISION

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SYMBOLS AND DEFINITIONS

Symbol	Definition
C_3	Twice the total energy per unit mass, so called the "VIS VIVA" by some. Specifically, $C_3 = V^2 - 2\frac{GM}{R}$, where V and R are referenced to some central body whose mass is denoted by M. The notations $C_{3\oplus}$, $C_{3☾}$, and $C_{3\odot}$ indicate that the central body is the earth, moon, and sun, respectively.
e	The eccentricity of the instantaneous two-body solution. Subscripts may be used as discussed for C_3.
i_M	Instantaneous inclination of the lunar travel plane relative to the true earth equator of date.
Ω_M	"The longitude of the mean ascending node of the moon's orbit measured in the ecliptic from the mean equinox of date"; see [3] for more details.
(ρ, δ, α)	Geocentric spherical coordinates of a body where ρ is the radial distance, δ is declination (the angle measured in the meridian containing the body from the earth's equator to the body, positive being north and negative south), α is right ascension (the angle measured in the equatorial plane from vernal equinox to the meridian containing the body, positive eastward).
r	Radial distance
ϕ'	Geocentric latitude
λ	Greenwich referenced longitude, positive eastward.
(V^*, V)	Velocity magnitude measured in a space-fixed and rotating system, respectively.
(Γ, γ)	Path angle referenced to the local horizontal plane, space-fixed and rotating, respectively.
(Σ, σ)	Local azimuth angle, space-fixed and rotating, respectively.

Symbol	Definition
h	Altitude
i	Inclination of a body's instantaneous plane of motion.
α_N	Right ascension of the ascending node of a body's instantaneous plane of motion.

SUBSCRIPTS

$\oplus$, ☾, $\odot$	Denote the central body as the earth, moon, or sun, respectively.
N	Denotes conditions of the ascending node.
M	Denotes conditions of the moon.
S	Denotes "selenographic" conditions; see [3] for details.

UNUSUAL TERMS

1. FLIGHT TIME or TRIP TIME denotes the time from injection to arrival at periselenum.

2. BALLISTIC TRANSIT implies that travel from a geocentric parking orbit to periselenum is made with no powered plane changes. Launch time variations are used to position the parking orbit, and coast time and burning time variations are used to establish the injection into the transit plane. The final stage is controlled during burning by a technique designated by Jet Propulsion Laboratory as "Control from the Horizon."

3. DUAL TIME SOLUTIONS refers to the two trajectories that are possible for arriving at the moon at a specified time, subject to the following constraints:

   a. Launch from Patrick Air Force Base at a due east azimuth.

   b. Utilize a circular parking orbit.

   c. Specify the TRIP TIME.

   d. Require BALLISTIC TRANSIT.

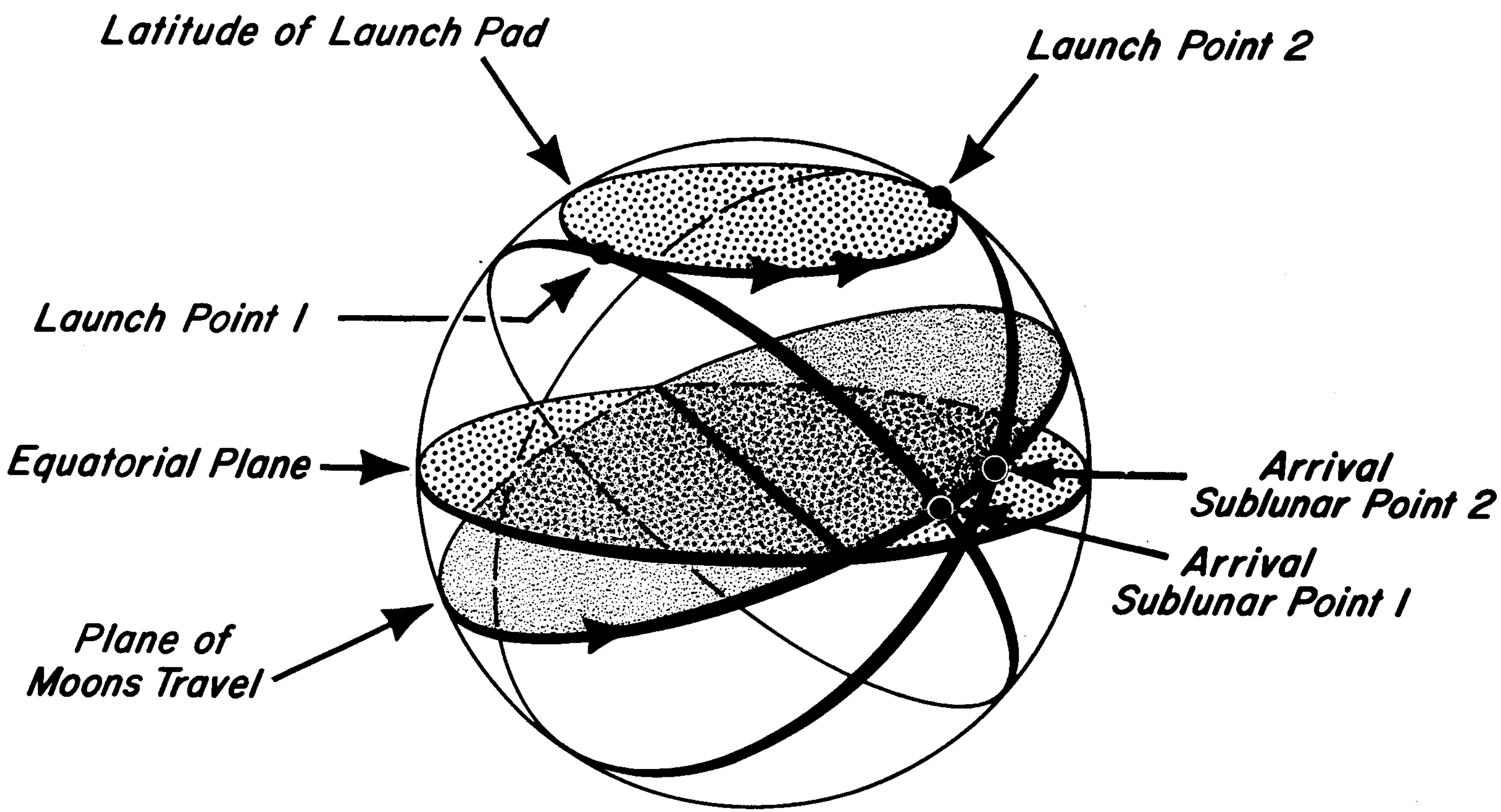

FIG. I. GEOMETRY OF THE DUAL-TIME SOLUTION FOR A DUE EAST LAUNCH AND NO POWERED PLANE CHANGES

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Figure 1 illustrates the geometry of the DUAL TIME SOLUTIONS but some pertinent details are not evident from the figure. Consider the infinity of parking orbit planes subject to the above constraints (all planes passing through earth's center and passing tangent to the injection latitude circle). Upon placing the moon, considered as a point, at some position in the volume swept out by this infinity of plane, one sees that, in general, two of these planes pass through the moon. Along the extremities (circular cones) of the volume swept out there is only one plane which passes through a given point. Thus, in general, one suspects that two trajectories are available for earth to moon transit, subject to the discussed constraints.

Let us now examine the situation to see if one can actually establish the two suspected trajectories. Since arrival time and trip time are to be identical for the two solutions, injection must occur at the same time. The time interval from liftoff to parking orbit is the same in any two cases. The burning time required to achieve injection from the parking orbit is essentially the same in the two cases due to the fixed distance to the moon (same arrival time), and the fixed central travel angle (same trip time). These considerations allow the injection time equality,

$$T_{INJ} = T_{L_1} + \Delta t_{L,PO} + \Delta t_{C_1} + \Delta t_{PO,I} = T_{L_2} + \Delta t_{L,PO} + \Delta t_{C_2} + \Delta t_{PO,I} ,$$

to be reduced to

$$T_{L_1} + \Delta t_{C_1} = T_{L_2} + \Delta t_{C_2},$$

where T_L is liftoff time, $\Delta t_{L,PO}$ is time from liftoff to parking orbit, Δt_C is coast time in parking orbit, and $\Delta t_{PO,I}$ is the time interval from parking orbit to injection.

Although T_{L1} and T_{L2} are not the same, they are fixed under the constraints, namely, that they result in two parking planes that contain the moon at arrival time. Finally then,

$$\text{CONSTANT} = T_{L_1} - T_{L_2} = \Delta t_{C_2} - \Delta t_{C_1},$$

must hold if the two solution trajectories exist. Since Δt_{C_2} and Δt_{C_1} must be utilized to place injection such that the central travel angle constraint is satisfied, it would be mere chance that the $(T_{L_1} - T_{L_2})$ equality were satisfied simultaneously. It should be noted, however, that theoretically one solution could be determined for arrival at the specified time. Another could be established whose arrival time would be in error by a fractional part of the period of the parking orbit. With reference to these two solutions we define and use the term "DUAL TIME SOLUTIONS."

4. <u>ARRIVAL CONIC</u> denotes the instantaneous two-body solution at arrival time with the moon as attracting body. The inclination and location of the conic is of primary interest in this report when referenced to the selenographic coordinate system. This system is discussed in [3].

5. $\bar{B}\cdot\bar{T}$ and $\bar{B}\cdot\bar{R}$ are operational scalars that are very useful in achieving various orientations of the arrival conic. A detailed discussion of these scalars is given in [7], but a brief generalized discussion is presented here.

The incoming asymptote of the selenocentric arrival conic is approximately parallel to the earth-moon line at arrival time. Denote a unit vector in the direction of the incoming asymptote as $\bar{S}$. The unit vector $\bar{T}$ is constructed to lie in the EARTH-MOON travel plane normal to $\bar{S}$ and positive toward the trailing edge of the moon. $\bar{R}$ is also normal to $\bar{S}$ and is given by $\bar{S} \times \bar{T}$. We see then that the plane defined by $\bar{R}$ and $\bar{T}$ is normal to $\bar{S}$. A vector $\bar{B}$, which is a function of the characteristics of the selenocentric arrival conic, lies in the $\bar{R}$ $\bar{T}$ plane and is called the "impact parameter." The magnitude of $\bar{B}$, $|\bar{B}|$, is related to close approach distance, R_{CA}, through the equation

$$|\bar{B}| = \sqrt{R_{CA}(2|a| + R_{CA})}$$

where $|a|$ is the magnitude of the semimajor axis of the arrival conic. One can see then that by specifying the desired projections of $\bar{B}$ onto $\bar{R}$ and $\bar{T}$, $\bar{B}\cdot\bar{T}$ and $\bar{B}\cdot\bar{R}$, it is possible to survey the arrival conic orientation about $\bar{S}$ for a given $|\bar{B}|$ or close approach distance.

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By Byrd Tucker

SUMMARY

The objective of this report is to provide accurately determined bounds for the effects of various parameters on departure velocity, periselenum arrival velocity, and the selenocentric arrival conic orientations. The various topics usually arise as questions closely akin to those set forth in the following. Answers to the questions presented are included and are the result of this study.

1. How much do <u>departure velocity</u> requirements change due to variations of the arrival earth-moon ephemeris and trip time variations in the 66 hour to 90 hour range? For arriving at the moon when it is at any position, the departure velocity requirements change is bounded by:

    a. 35(m/s) for flights of 66 hours

    b. 22(m/s) for flights of 78 hours

    c. 20(m/s) for flights of 90 hours.

The overall bound for all arrival ephemeris variations and all trip times in the 66 to 90 hour range is 55(m/s). These bounds are determined by projecting all injection conditions (which occurred at slightly varied altitudes) to a mean radius of 6770(km).

2. How much do <u>departure velocity</u> requirements change with different trajectory approach paths such as direct, retrograde, or polar approaches? The complete range of possible approach paths can only change the departure velocity by about 4(m/s).

3. What effect does varying the selenocentric arrival altitude have on <u>departure conditions</u>? Essentially NONE! The injection conditions,

position vector and velocity vector, are essentially invariant for arrival altitude changes in the 50(km) to 500(km) altitude range (approach path being frozen).

4. How does arrival velocity vary due to changes in arrival altitude?

$$\frac{\partial \text{ (ARRIVAL VELOCITY)}}{\partial \text{ (ARRIVAL ALTITUDE)}} \approx -1 \text{ (m/s/n.m.)} \approx -.54\text{(m/s/km)}$$

5. How much does arrival velocity change for various combinations of arrival time (earth-moon positions) and trip times?

a. The effect of all combinations of arrival times and trip times in the 66 to 90 hour range is bounded by 200(m/s).

b. For trip time frozen at 66 hours, the varying earth-moon ephemeris effect is bounded by 105(m/s), at 78 hours the bound is 70(m/s), and at 90 hours the bound is 55(m/s).

6. The arrival velocity magnitude varies by about 10(m/s) for the various approach paths when arrival altitude and flight time are held constant.

In the following, inclination refers to the inclination of the arrival conic relative to the moon's equator. All the following results are for flights making no powered plane changes and having 66 hour trip time.

7. There are inclinations in the neighborhood of 0° and 180° that cannot be established for any arbitrary arrival time.

8. For retrograde flights (those arriving counter to or against the moon's motion, i.e., those having inclinations greater than 90°) the unattainable inclination area around 180° is bounded by about 7°.

9. Generally speaking, when the moon is at its maximum or minimum declination, the unattainable inclination area around 180° shrinks to less than 1°. When the moon is near zero declination, the unattainable area peaks at about 7°.

The basic trajectory data for this study were generated using a space flight program that was obtained from Jet Propulsion Laboratory. To our knowledge, this program is as accurate as any available to NASA installations.

SECTION I. INTRODUCTION

The establishment of optimum or near optimum techniques for performing various lunar missions is a current, pressing problem. Upon the introduction of optimization concepts for performing such missions, the effects of various parameters that have been considered insignificant outside the realm of optimization must be evaluated. Further, care must be exercised that simplifying assumptions and numerical inaccuracies are tolerable. Working in accordance with these views, it has been impossible to use some apparently relevant results from different works because insufficient information was available as to their accuracy.

The objective of this publication is to establish bounds for a few of the parameters of the problem, and to furnish some information for "Trade-off" considerations to serve as basis for choosing one technique rather than another.

SECTION II. CONSTRAINTS AND IMPLEMENTS OF THE STUDY

The trajectory simulations were performed on an IBM 7090 Space Flight Program which was obtained from the Jet Propulsion Laboratory. The program includes the effects of the oblate earth, sun, triaxial moon, and Jupiter. A comprehensive discussion of the program is presented in Reference 1*. The various geophysical, astronomical, and operational constants required by the program are discussed in [1] and [4]. The constants used in this study are those currently in use at Jet Propulsion Laboratory, according to [1] and [4].

The numerical errors incurred by the computational procedures are well controlled. Reference 5 indicates that such error in periselenum arrival position is not more than 100 meters. Information, again from [5], on periselenum arrival velocity is vague, but indications are that the numerical error is in the seventh digit.

This study is concerned with the flight phase from a geocentric circular parking orbit to arrival at periselenum.

SECTION III. COMMENTS ON SOME CHARACTERISTICS OF THE MOON'S MOTION

References 2 and 3 present a great deal of information about the moon's motion. Reference 2 presents, primarily, graphical information. Reference 3 gives explanatory discussions and the derivation of some equations of interest.

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*References will be denoted by "Reference numbers" or bracketed [ ] numbers in the text and refer to specific entries in the table of references in this report.

Extracting from Reference 2, the following information is restated here since it has direct influence upon some phases of this study:

1. The geocentric radial distance to the moon at its . . .

   a. Apogees varies by about .4 earth radius or 2550 (km)

   b. Perigees varies by about 2 earth radii or 12750 (km).

   The conversion to kilometers is made assuming an earth radius to equal 6370 (km).

2. The times at which absolute perigees or "local-minimum-distance" perigees occur from a sequence, (T_i), such that as $i = 1, 2 \ldots n$,

$$\left(T_1 = T_0 + 7^{Mo},\ T_2 = T_1 + 8^{Mo},\ T_3 = T_2 + 7^{Mo},\ T_4 = T_3 + 8^{Mo},\ \ldots,\right.$$

$$\left. T_n = T_{n-1} + \begin{matrix}(7)^{Mo}\\(8)\end{matrix}\right).$$

3. The graphs of lunar declination ($\delta_{☾}$) and geocentric radial distance ($\rho_{☾}$) versus date indicate that the $\delta_{☾}$ and $\rho_{☾}$ plots are . . .

   a. out-of-phase by about 180° in November 1964

   b. out-of-phase by about 90° in October 1966

   c. approximately in-phase in March 1969.

4. In March 1969, the declination of the moon takes on its maximum value, i.e., about 28.7°.

5. The ephemeris of the moon's motion relative to the earth is, for all practical purposes, periodic; the period is approximately 18.5 years.

IV. BOUNDS FOR THE EFFECT OF THE VARYING EARTH-MOON EPHEMERIS ON DEPARTURE AND ARRIVAL VELOCITIES FOR VARIOUS TRIP TIMES

1. PROCEDURE

It is desirable to know just what differences are the result of performing a lunar mission at one time rather than another. The present objective is to set forth the differences which occur in departure and arrival velocities.

The cyclic nature of the moon's motion in about each eighteen and one-half years exhibits the following characteristics:

ρ - geocentric radial distance - takes on essentially all possible values each seven or eight months.

δ - declination - goes through a relative maximum to minimum cycle each month but takes on an absolute maximum and minimum in about eighteen and one-half years.

α - right ascension - takes on all possible values once each month.

A sampling of the earth-moon ephemeris is desired that will result in the indicated bounds on departure and arrival velocities. This sampling was taken to be the ten cases whose characteristics are set forth in Table 1. The sampling ranges over about 99.4% of all possible values for ρ, radial distance to the moon, but only the values of δ, declination of the moon, from about $\pm 24°$ to $\pm 28.7°$. All possible phase combinations of ρ and δ are covered by the sampling.

As one might expect, the sampling taken is adequate to determine bounds for departure and arrival velocities. The lack of coverage in the δ range is of no consequence.

Actual trajectory surveys were made for arrival at the moon in the neighborhood of our ephemeris sampling. The TRIP TIME and ARRIVAL CONIC were specified for each trajectory. This was accomplished by specifying the desired trip time, $\bar{B} \cdot \bar{T}$, and $\bar{B} \cdot \bar{R}$ (Reference 7) quantities, and searching for the combination of launch time, coasting time, and final stage burning time that resulted in the desired quantities.

TABLE 1

ARRIVAL CHARACTERISTICS OF THE EARTH-MOON EPHEMERIS SAMPLING

Time MM, DD, YY; HH	Geocentric Radial Distance to the Moon ρ_M (km)	Declination of the Moon δ_M (deg)	Instantaneous Inclination of Moon's Travel Plane to Earth's Equator i_M (deg)	Ascending Node of Moon's Travel Plane Referenced to Vernal Equinox in the Earth's Equatorial Plane	Ascending Node of Moon's Travel Plane Referenced to Vernal Equinox in the Ecliptic Plane
Nov 10, 64; 08	404331 (~ APO)	-23.9 (~ MIN)	24.56	12.56	-275.29
Nov 22, 64; 05	360984 (~ PERI)	24.5 (~ MAX)	24.61	12.62	-275.91
Nov 30, 64; 03	394139	-5.1 (~ ZERO)	24.61	12.65	-276.33
Oct 7, 66; 07	380198	27.2 (~ MAX)	27.28	8.29	-312.14
Oct 13, 66; 18	359253 (~ PERI)	-3.0 (~ ZERO)	27.30	8.26	-312.48
Oct 20, 66; 08	391409	-27.0 (~ MIN)	27.33	8.31	-312.83
Oct 27, 66; 04	404193 (~ APO)	.4 (~ ZERO)	27.34	8.29	-313.19
Mar 12, 69; 20	369413 (~ PERI)	-27.9 (~ MIN)	28.72	.35	-359.14
Mar 18, 69; 18	381691	3.0 (~ ZERO)	28.72	.34	-359.45
Mar 26, 69; 20	403566 (~ APO)	27.5 (~ MAX)	28.72	.34	-359.88

2. RESULTS

A. Effects of Various Arrival Patterns on Velocities

How much do the velocity requirements change with a change in the orientation of the arrival conic? This question arises quite frequently in terms of the feasibility of retrograde (opposite in direction to moon's motion), direct (with the moon's motion), or polar orbits.

Four trajectories are sufficient as basis for answering this question, each trajectory having a specified approach path. Figure 2 presents a selenocentric (moon-centered) plot of the arrival portion of two of these basic trajectories. The xy plane is coincident with the true equatorial plane of date, the x-axis being in the direction of the true equinox of date. This system shall be referred to as the "Selenocentric True Ephemeris System of Date."

Table 2 lists pertinent departure and arrival conditions.

TABLE 2

DEPARTURE AND ARRIVAL CONDITIONS FOR VARIOUS ARRIVAL CONIC ORIENTATIONS IN NOVEMBER 1964

Geocentric Departure Conditions

Radius r (km)	Latitude $\emptyset'$ (deg)	East Longitude λ (deg)	Inertial Velocity V^* (m/s)	Path Angle Γ (deg)	Azimuth Σ (deg)	Arrival Path Identification
6792.4	15.98	333.81	10788.4	6.85	113.65	Retro - Orbital: I
6792.1	16.22	333.26	10784.5	6.84	113.49	Direct - Orbital: II
6792.0	15.28	335.34	10786.8	6.84	114.10	Polar - Over: III
6792.5	16.95	331.60	10786.4	6.85	112.98	Polar - Under: IV

Selenographic* Periselenum Arrival Conditions 66^{hr} Trip Time

Radius r_s (km)	Latitude $\emptyset'_s$ (deg)	Longitude λ_s (deg)	Space-Fixed Velocity V^*_s (m/s)	Rotating Azimuth σ_s (deg)	Space-Fixed Azimuth Σ_s (deg)	Inclination To Earth's Equator $i_\oplus$ (deg)	Arrival Path ID
1922.7	-3.42	190.12	2569.3	276.29	261.28	156.73	I
1897.2	7.01	87.78	2575.8	91.99	113.06	23.26	II
1910.1	53.63	147.55	2572.3	191.27	193.62	101.72	III
1909.3	-48.03	131.09	2572.8	98.96	33.16	78.33	IV

*A detailed discussion of Selenographic coordinates is given in [3].

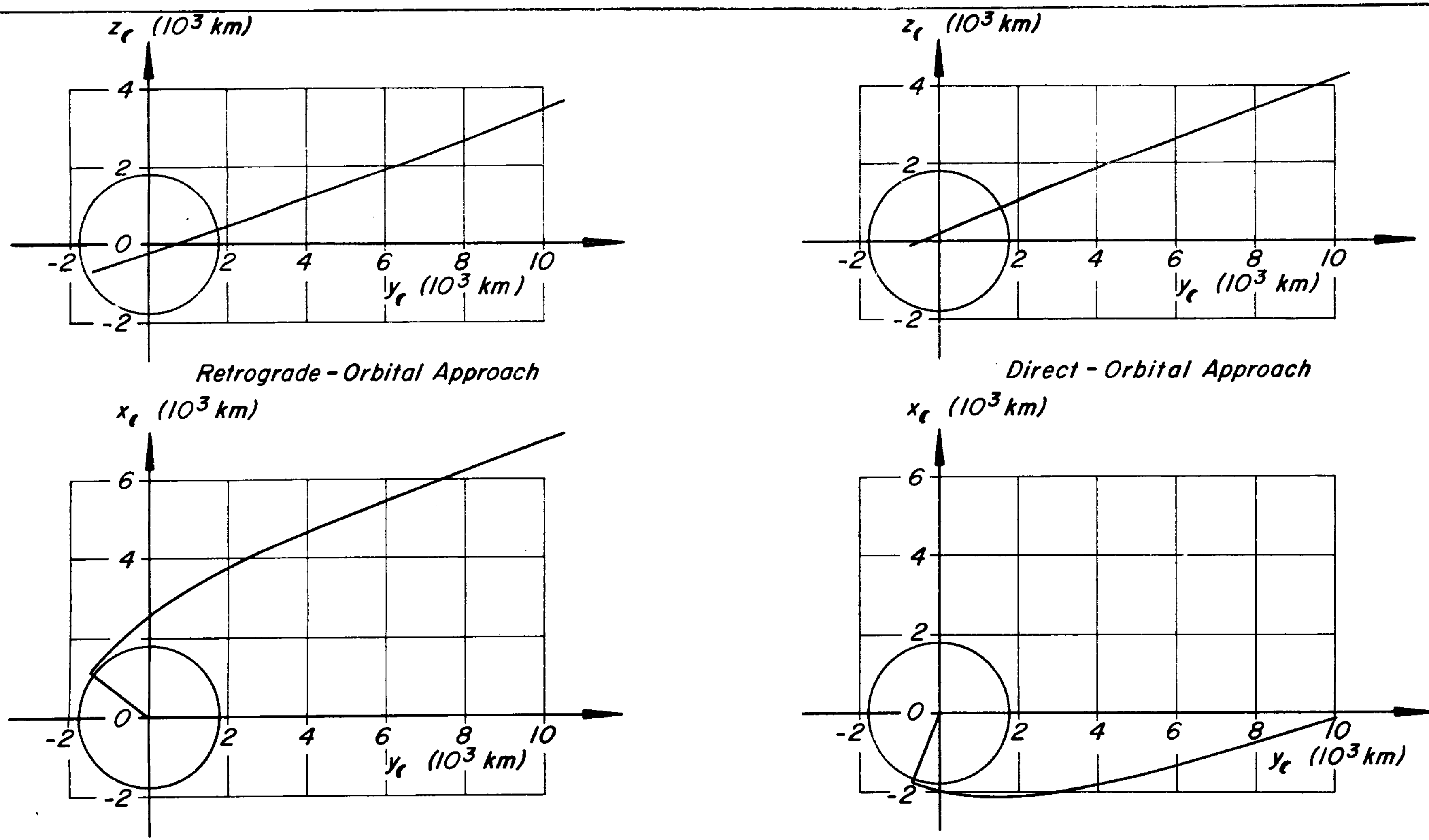

FIG. 2. VARIOUS ARRIVAL CONIC ORIENTATION TRAJECTORY PLOTS IN SELENOCENTRIC TRUE EPHEMERIS COORDINATES OF DATE

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From the data presented in Table 2, one can conclude that -

1. The changes in departure velocity magnitude due to various arrival paths are bounded by about 4 (m/s).
2. By applying the partials relationship given on page 9 to the V_s^* and r_s data of Table 2, one finds that the arrival velocity magnitude varies by about 10(m/s) for all variations in arrival conic orientations on trajectories having constant flight time and arrival altitude.

B. VELOCITY VARIATIONS DUE TO VARYING THE ARRIVAL ALTITUDE

The basic trajectory data needed here is presented in Table 3. Three trajectories were determined to arrive at essentially the same time, along the same arrival path (RETROGRADE - ORBITAL), and all having the same trip time, 66 hours. However, in each case arrival is at a different periselenum altitude.

TABLE 3

DEPARTURE AND ARRIVAL CONDITIONS FOR ARRIVING AT VARIOUS PERISELENUM ALTITUDES VIA A FIXED ARRIVAL PATH IN OCTOBER, 1966

Geocentric Departure Conditions

Radius r (km)	Latitude $\emptyset'$ (deg)	East Longitude λ (deg)	Inertial Velocity V (m/s)	Path Angle Γ (deg)	Azimuth Σ (deg)	Trajectory ID
6780.5	-6.06	14.28	10767.0	6.72	117.70	ALT - 1
6780.5	-6.07	14.29	10767.0	6.72	117.70	ALT - 2
6780.4	-6.07	14.30	10767.1	6.72	117.69	ALT - 3

Selenographic* Periselenum Arrival Conditions, 66^{hr} Trip Time

Radius r_s (km)	Altitude h_s (km)	Latitude $\emptyset'_s$ (deg)	Longitude λ (deg)	Velocity V_s (m/s)	Azimuth σ_s (deg)	Trajectory ID
1865.8	127.8	9.25	177.25	2578.9	281.35	ALT - 1
1965.3	227.3	9.06	178.18	2527.1	281.49	ALT - 2
2069.7	331.7	8.87	179.12	2471.9	281.63	ALT - 3

The data of Table 3 emphasizes the fact that all arrival altitudes in the desired range of values require the same departure velocity vector. In fact the complete specification of departure position and velocity vectors is essentially invariant for all values of arrival altitude that come under present consideration, ranging from about 50 (km) to about 500 (km).

*The Selenographic coordinate system is moon-centered and rotates such that one axis is always in the general direction of the earth; see [3] for details.

C. DEPARTURE AND ARRIVAL VELOCITY BEHAVIOR FOR CHANGES IN ARRIVAL EARTH-MOON EPHEMERIS AND TRIP TIME

The trajectory data of this section was generated subject to the following constraints:

a. Launch from Patrick AFB at a due east azimuth.

b. A parking orbit is utilized.

c. BALLISTIC TRANSIT is used.

d. The arrival path is always retrograde to the moon's motion and essentially in the plane of earth-moon motion, so-called the RETROGRADE ORBITAL approach.

The velocity behavior is to be examined for variations in trip time and the earth-moon ephemeris at arrival (arrival time).

1. DEPARTURE VELOCITY

First, let us recall the results already established concerning departure velocity behavior:

1. The complete range of all possible arrival conic orientations causes the departure velocity to change by about 4 (m/s), Table 2.

2. The RETROGRADE ORBITAL approach region is the most expensive, i.e., these approaches require greater departure velocity than the other approach regions, Table 2.

3. Departure velocity is essentially independent of the periselenum arrival altitude in the altitude range of interest, from about 50 (km) to about 500 (km).

Figure 3 illustrates the departure velocity behavior for RETROGRADE ORBITAL approach paths (most expensive approach). One can conclude from Figure 3 that -

4. The departure velocity spread for arriving at any earth-moon ephemeris with trip times ranging from 66 hours through 90 hours is about 55 (m/s). For frozen flight times of (a) 66 hours the spread is about 35 (m/s), (b) 78 hours it is about 21 (m/s), and (c) 90 hours it is about 20 (m/s).

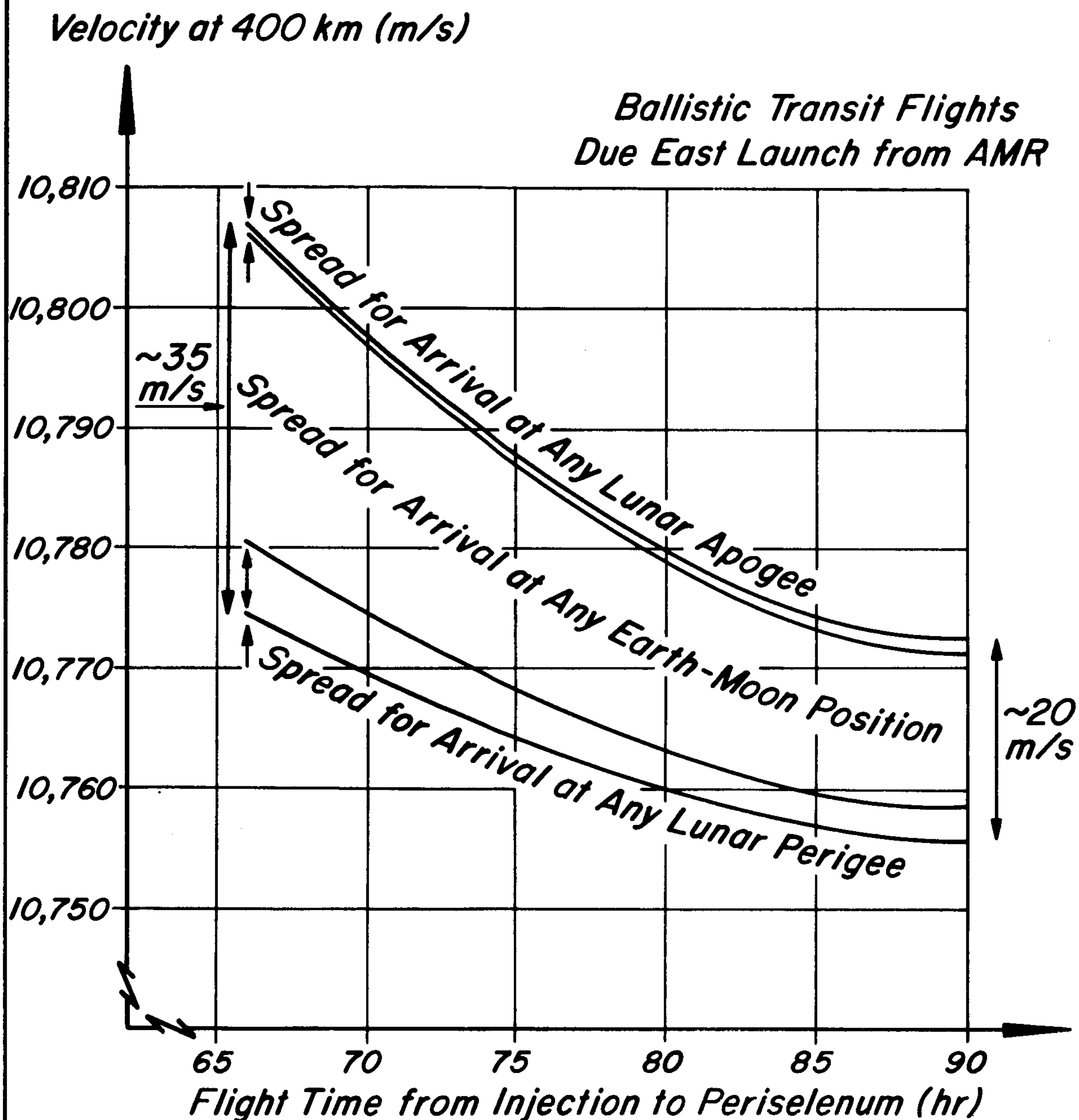


FIG. 3. DEPARTURE VELOCITY AT A GEOCENTRIC ALTITUDE OF 400 KM THAT RESULTS IN LOW ALTITUDE PERISELENUM ARRIVAL FOR VARIOUS FLIGHT TIMES AND EARTH-MOON POSITIONS AT ARRIVAL

2. ARRIVAL VELOCITY

Figure 4 and Table 4 present the pertinent data for this discussion:

From the differences of Table 4, the effect on arrival velocity due to varying arrival periselenum altitude is seen to be about -1 (m/s) per nautical mile in altitude, i.e.,

$$\frac{\partial\ (\text{ARRIVAL VELOCITY})}{\partial\ (\text{ARRIVAL ALTITUDE})} \approx -1\ (\text{m/s/n.m.}) \approx -.54\ (\text{m/s/km})$$

Figure 4 illustrates the bounds on the effects due to variations in trip time and positions of earth-moon ephemeris. Having established the partial relationship just mentioned, the following bounds for arrival velocity at any 50 (km) to 500 (km) arrival periselenum altitude may be stated:

> Arrival velocity varies by less than 200 (m/s) for any combination of arrival earth-moon ephemeris and trip times in the 66 hour to 90 hour range. For specific trip times the bounds are (a) 105 (m/s) for 66 hour trips, (b) 70 (m/s) for 78 hour trips, and (c) 55 (m/s) for 90 hour trips.

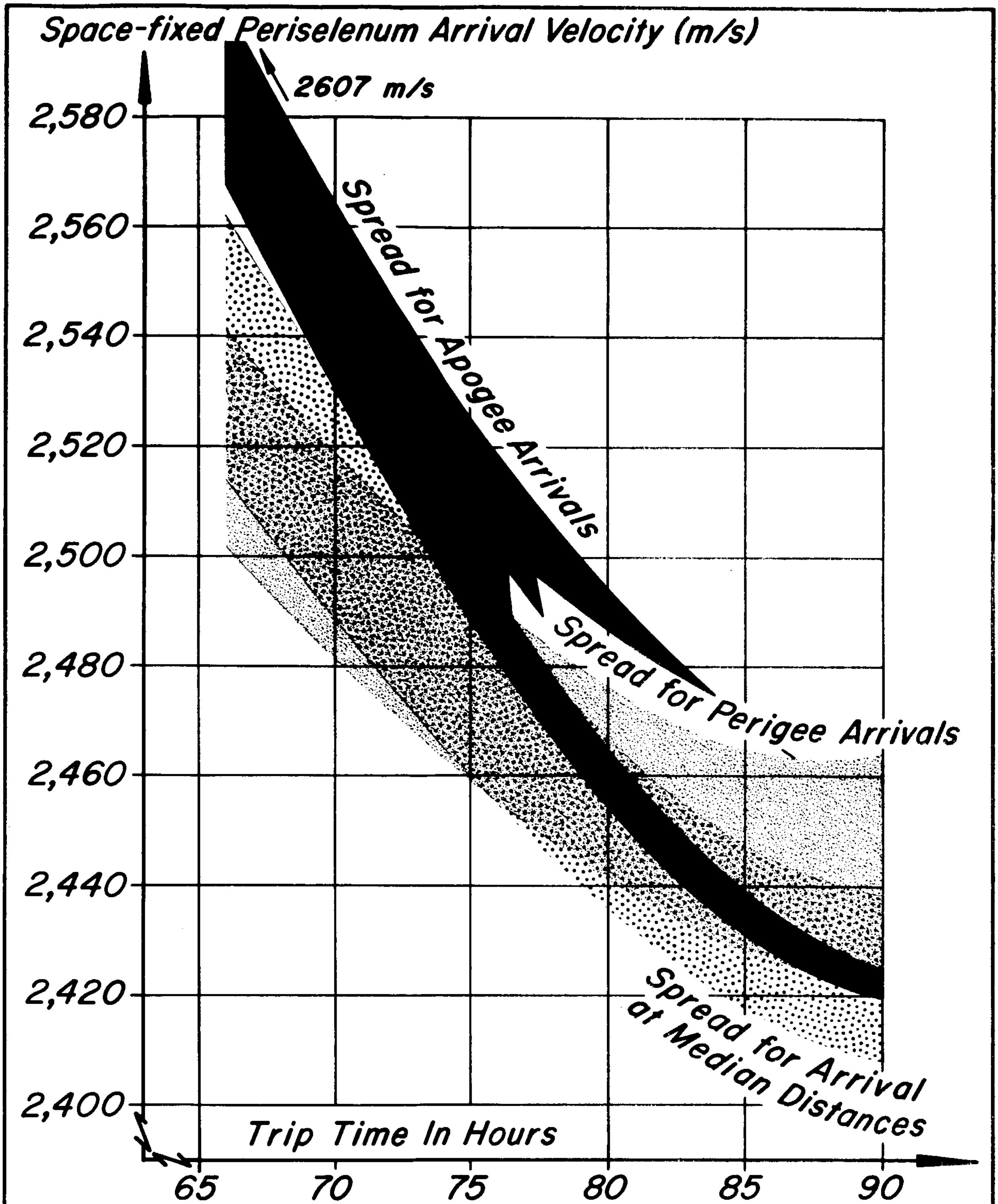


FIG. 4. VELOCITY FOR ARRIVAL AT 185 KM PERISELENUM ALTITUDE FOR VARIOUS TRIP TIMES AND EARTH-MOON EPHEMERIS SAMPLINGS

TABLE 4

SPACE-FIXED ARRIVAL VELOCITY FOR VARIOUS (1) PERISELENUM ARRIVAL ALTITUDES, (2) TRIP TIMES, AND (3) SAMPLINGS OF THE EARTH-MOON EPHEMERIS AT ARRIVAL

Arrival* Date MM, DD, YY	SPACE-FIXED ARRIVAL VELOCITY IN (m/s)								
	Trip Time = 66 (HRS)			Trip Time = 78 (HRS)			Trip Time = 90 (HRS)		
	h_s=140(km) h_s= 75(n.m)	h_s=185(km) h_s=100(n.m)	h_s=230(km) h_s=125(n.m)	h_s=140(km) h_s= 75(n.m)	h_s=185(km) h_s=100(n.m)	h_s=230(km) h_s=125(n.m)	h_s=140(km) h_s= 75(n.m)	h_s=185(km) h_s=100(n.m)	h_s=230(km) h_s=125(n.m)
VELOCITIES FOR ARRIVAL AT SELECTED LUNAR APOGEES									
11, 10, 64	2598	2580	2562	2502	2478	2455	2452	2425	2400
10, 27, 66	2592	2569	2548	2496	2472	2448	2444	2420	2396
03, 26, 69	2592	2568	2544	2491	2467	2443	2446	2421	2398
VELOCITY FOR ARRIVAL AT SELECTED LUNAR MEDIAN DISTANCES									
11, 30, 64	2586	2562	2540	2502	2478	2455	2463	2438	2414
10, 07, 66	2570	2546	2523	2489	2466	2442	2451	2425	2402
10, 20, 66	2546	2521	2497	2473	2448	2424	2433	2408	2384
03, 18, 69	2537	2514	2492	2468	2445	2421	2439	2414	2390
VELOCITIES FOR ARRIVAL AT SELECTED LUNAR PERIGEES									
11, 22, 64	2526	2502	2480	2472	2448	2426	2450	2425	2400
10, 14, 66	2566	2541	2519	2506	2483	2459	2488	2464	2440
03, 12, 69	2541	2517	2494	2479	2454	2430	2447	2423	2399
AVERAGE VELOCITIES FOR ARRIVAL AT . . .									
Apogees	2594	2572	2551	2496	2472	2449	2447	2422	2398
Medians	2560	2536	2513	2483	2459	2436	2447	2421	2398
Perigees	2544	2520	2498	2486	2462	2438	2462	2437	2413

DIFFERENCES IN ARRIVAL VELOCITY DUE TO CHANGES IN ARRIVAL ALTITUDE.

	$V_{100} - V_{75}$	$V_{125} - V_{100}$	$V_{100} - V_{75}$	$V_{125} - V_{100}$	$V_{100} - V_{75}$	$V_{125} - V_{100}$
Apogees	-22	-21	-24	-23	-25	-26
Medians	-24	-23	-24	-23	-26	-27
Perigees	-22	-22	-24	-24	-25	-24

*See Table 1 for the characteristics of the Earth-Moon Ephemeris sampling.

SECTION V. BOUNDS FOR THE ATTAINABLE ARRIVAL CONIC ORIENTATIONS

For this discussion, the arrival conic orientation is taken relative to the moon's equator. More specifically, the orientation shall be specified by the inclination relative to the moon's equator, i_S, and the selenographic longitude of the ascending node, Ω_{NS}.

The establishment of bounds for the achievable arrival conic orientations subject to a given set of constraints is the principle objective of this section. At the same time some interesting characteristics of the arrival conic behavior will be mentioned.

1. PROCEDURE

The basic approach has been to survey the behavior of the arrival conic orientation subject to the constraints listed at the beginning of section IV-C, page 10, of this report. Two other arrival constraints are imposed for these results:

1. Trip time is required to be 66 hours.

2. Arrival altitude is held in the 100 (km) to 200 (km) range.

Operationally the described procedure is accomplished by specifying position and velocity vectors at the parking orbit initiation which satisfy the launch constraints, and searching for the launch time, coast time, and final stage burning time combination which results in the desired arrival constraints. The arrival constraints are formulated in terms of $\bar{B}\cdot\bar{T}$, $\bar{B}\cdot\bar{R}$, and flight time, T_F. The magnitude of the B vector, $|\bar{B}|$, controls arrival altitude and $\bar{B}\cdot\bar{T}$ and $\bar{B}\cdot\bar{R}$ combinations result in various conic orientations for a given magnitude of the miss vector, i.e., $|\bar{B}|$.

It should be recalled that there are TWO SOLUTIONS IN TIME (generally speaking) for arriving at the moon when it is in the proximity of some specified earth-moon position. During this phase of the study it became apparent that the two solutions behaved somewhat differently; hence, both branches of the "DUAL-TIME SOLUTION" are presented.

The three months represented in the EARTH-MOON EPHEMERIS SAMPLING whose characteristic data are presented in Table 2 are used as samplings for this phase of the study also.

2. RESULTS

The behavior of the departure and arrival conditions, as a survey of $\bar{B} \cdot \bar{T}$ and $\bar{B} \cdot \bar{R}$ combinations is made (for a given $\bar{B}$ magnitude), is quite interesting. A tabulation of these data is presented in Tables 5 and 6. The data of Table 5 result from retrograde approach flights with polar approaches at the extremes of the survey. Table 6 data are from direct approach flights, the survey being terminated short of the polar extremes.

One can observe from the i_S data of Tables 5 and 6 that arrival inclinations from about 174° to 180° (Table 5) as well as from about 0° to 18° (Table 6) are not attainable for that particular class of trajectories. Immediately questions begin coming to mind as to the reasons for the existence of such "DEAD INCLINATION AREAS," a term that shall be used to denote the unattainable areas, and the influence that various parameters have on their existence and behavior. This report does not deal exhaustively with these questions but does present some helpful results. The results are empirical in nature and no attempt is made to present any analytic evaluation of the problems.

A. The influence of the Varying Earth-Moon Ephemeris At Arrival

Four distinct sets of trajectories have been run, and, in view of the results to be presented, it is convenient to describe the sets as follows:

a. Each set consists of trajectories resulting in the minimum attainable i_S for both branches of the DUAL-TIME SOLUTION as the arrival time is stepped through a specified era.

b. In three of the four sets launch is from Patrick AFB at a due east azimuth resulting in a BALLISTIC TRANSIT plane inclined at about 28.3° to the earth's equator. In the other set, a fictitious launch site is assumed such that a due east launch results in a BALLISTIC TRANSIT plane inclined at about 24.4° to the earth's equator. This manipulation was done to produce two sets having the BALLISTIC TRANSIT plane near coplanar with the moon's travel plane.

TABLE 5

DEPARTURE AND ARRIVAL CONDITIONS FOR VARIOUS RETROGRADE ARRIVAL CONIC ORIENTATIONS FIXED FLIGHT TIME OF 66^{hrs}, AND FIXED $|\bar{B}|$

Launch Time MM, DD, HH, MIN, SEC	Coast Time Sec	Burn Time Sec	i Deg	Ω_N Deg	ϕ' Deg	λ Deg	h km	Γ Deg	Σ Deg	V^* m/s
Arrival Time MM, DD, HH, MIN, SEC	**B·T (km)**	**B·R (km)**	**i_s Deg**	**Ω_{Ns} Deg**	**ϕ'_s Deg**	**λ_s Deg**	**h_s km**	**$i_\oplus$ (Deg)**	**σ_s Deg**	**V^*_s m/s**
11, 27, 07, 57, 55.81	3840.94	366.98	28.294	15.839	15.359	200.839	407.19	6.938	65.943	10785.3
11, 30, 03, 17, 38.69	0	-4081	88.605	-37.040	53.530	141.072	37.78	110.993	177.653	2609.3
11, 27, 07, 56, 45.30	3850.64	367.09	28.293	15.544	15.626	201.423	407.51	6.942	66.110	10786.4
11, 30, 03, 16, 26.25	-2769	-3000	131.044	-42.304	38.623	181.770	51.35	151.877	237.190	2603.8
11, 27, 07, 55, 35.04	3856.23	367.12	28.293	15.250	15.779	201.757	407.65	6.943	66.207	10786.6
11, 30, 03, 16, 32.36	-3555	-1999	148.729	-47.037	26.587	188.457	50.38	166.018	252.899	2604.9
11, 27, 07, 53, 24.89	3864.39	367.14	28.293	14.706	15.999	202.245	407.84	6.943	66.351	10786.8
11, 30, 03, 13, 21.55	-4075	-200	172.620	-91.985	7.184	191.313	54.74	158.092	271.693	2602.9
11, 27, 07, 53, 10.27	3865.21	367.14	28.293	14.645	16.021	202.293	407.86	6.943	66.365	10786.8
11, 30, 03, 13, 07.80	-4081	0	173.778	-113.781	5.103	191.220	55.03	155.682	273.564	2602.8
11, 27, 07, 52, 33.75	3867.17	367.14	28.293	14.492	16.074	202.410	407.89	6.943	66.400	10786.7
11, 30, 03, 12, 55.61	-4049	499	171.750	-169.870	-.076	190.658	54.07	149.370	278.250	2603.2
11, 27, 07, 52, 11.81	3868.30	367.14	28.293	14.401	16.104	202.477	407.91	6.943	66.420	10786.7
11, 30, 03, 13, 01.60	-4001	799	168.438	174.311	-3.186	190.100	53.34	145.420	281.120	2603.5
11, 27, 07, 50, 41.91	3872.26	367.12	28.293	14.025	16.209	202.712	407.96	6.942	66.490	10786.4
11, 30, 03, 10, 47.85	-3560	2000	151.511	154.312	-15.913	186.003	54.20	128.211	293.945	2602.7
11, 27, 07, 49, 25.64	3874.77	367.09	28.293	13.706	16.275	202.860	407.97	6.941	66.534	10786.0
11, 30, 03, 09, 31.89	-2767	3000	133.841	148.826	-27.223	178.433	49.45	110.74	308.836	2604.8
11, 27, 07, 47, 55.96	3873.89	366.98	28.293	13.331	16.247	202.798	407.81	6.937	66.515	10784.8
11, 30, 03, 08, 22.95	1	4081	91.487	142.939	-41.396	144.250	36.56	69.017	358.018	2609.9

TABLE 6

DEPARTURE AND ARRIVAL CONDITIONS FOR VARIOUS DIRECT ARRIVAL CONIC ORIENTATIONS
FIXED FLIGHT TIME OF 66^{hrs}, AND FIXED $|\bar{B}|$

Launch Time MM, DD, HH, MIN, SEC	Coast Time Sec	Burn Time Sec	i Deg	α_N Deg	ϕ' Deg	λ Deg	h km	Γ Deg	Σ Deg	V^* m/s
Arrival Time MM, DD, HH, MIN, SEC	**B·T (km)**	**B·R (km)**	**i_s Deg**	**Ω_{Ns} Deg**	**ϕ Deg**	**λ_s Deg**	**h_s km**	**$i_{\oplus}$ (Deg)**	**σ_s Deg**	**V_s^* m/s**
11, 27, 21, 55, 10.23	746.23	367.07	28.30	225.97	-2.885	8.702	405.97	6.785	118.17	10785.5
11, 30, 16, 22, 58.04	3535.53	-1999.76	31.42	343.51	30.52	88.76	154.89	54.39	114.46	2571.9
11, 27, 21, 55, 37.55	742.45	367.065	28.30	226.08	-2.765	8.494	406.01	6.785	118.18	10785.4
11, 30, 16, 23, 13.39	3936.49	-999.79	18.92	4.772	18.806	88.13	154.20	40.38	101.17	2572.2
11, 27, 21, 57, 07.82	734.23	367.08	28.30	226.46	-2.506	8.004	406.13	6.7855	118.20	10785.4
11, 30, 16, 24, 44.21	3936.52	1000.26	20.14	99.69	-2.685	92.34	156.26	18.73	82.42	2571.5
11, 27, 22, 07, 36.46	729.71	367.10	28.30	226.73	-2.364	7.798	406.22	6.786	118.21	10785.6
11, 30, 16, 26, 30.95	3535.59	1999.61	32.94	118.84	-13.35	97.36	158.43	17.70	73.21	2570.8

c. The four sets are characterized as follows:

Transit Plane Inclination, $i_{\oplus}$	Moon's Travel Plane Inclination, $i_{\oplus M}$	Arrival Time Era	Set Identification
24.4°	24.5°	Nov-Dec, 1964	Travel-Plane Transit (-.1)
28.3°	28.7°	Mar-Apr, 1969	Travel-Plane Transit (-.4)
28.3°	27.3°	Oct, 1966	Out-of-Plane Transit (1.0)
28.3°	24.5°	Nov-Dec, 1964	Out-of-Plane Transit (3.8)

Figures 5 and 6 and Tables 7 through 10 present the data for the TRAVEL-PLANE TRANSIT CASES. Some results may be pointed out quite readily from Figures 5 and 6:

1. The DUAL-TIME SOLUTION separates into a high minimum inclination branch (peaks at about 13° to 14°) and a low minimum inclination branch (peaks at about 7°). However, one should observe that the high branch does on occasion drop to a lower declination than the so-called low branch.

2. Inclinations of near zero are attainable when the $\delta_{\mathbb{C}}$ at arrival is near maximum or minimum. For arrival $\delta_{\mathbb{C}}$ around zero, the minimum inclinations are in the peak regions; i.e., around 7° is the minimum that can be obtained.

In Tables 7-14, the data designated as $\Delta\alpha_{\oplus N}$ represents the deviation of right ascension of the ascending node of the vehicle's transit conic (at injection) from the right ascension of the moon's travel plane at that time, i.e., $\Delta\alpha_{\oplus N} = \alpha_{\oplus N} - \alpha_{\oplus M}$. From this then one can conclude that:

3. The branch having low peaks is a near coplanar solution whereas the branch having high peaks would be considered an out-of-plane solution.

Figures 7 and 8 and Tables 11 through 14 present the results for the two OUT-OF-PLANE TRANSIT CASES. Figures 7 and 8 and Tables 11 through 14 show that for these cases:

4. The DUAL-TIME SOLUTION does not separate (as in the TRAVEL-PLANE TRANSIT CASES) into a high and low inclination branch. Rather each branch has a high peak and a low peak, the peaks being in the 7° and 14° neighborhood.

In these cases as was pointed out for the two previous cases:

5. Inclinations near zero are attainable when the $\delta_{\mathbb{C}}$ at arrival is near maximum or minimum. For arrival $\delta_{\mathbb{C}}$ in the neighborhood of zero, the minimum inclinations are in the peak regions.

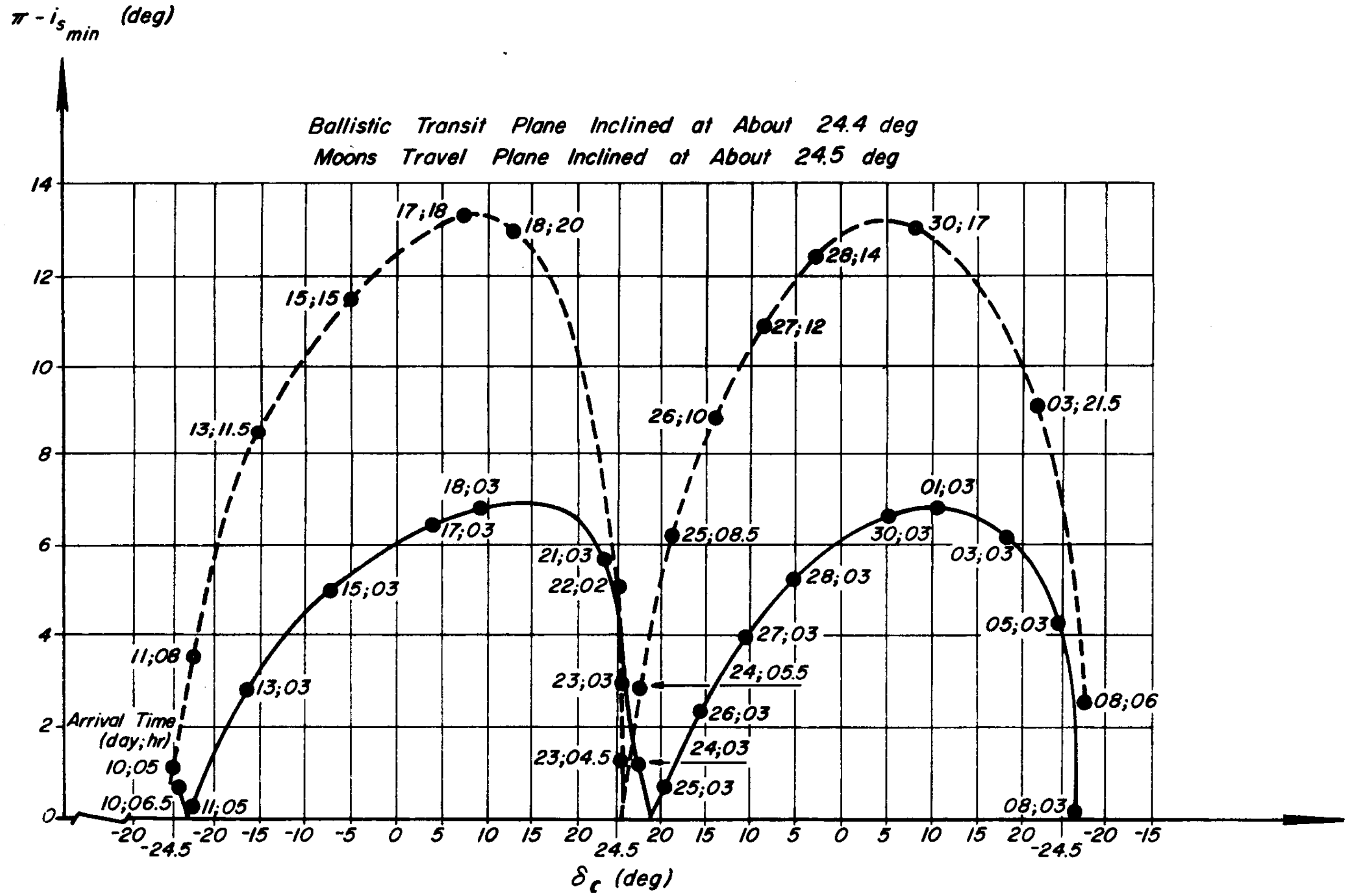


FIG. 5. MINIMUM ATTAINABLE (i_S) FOR THE DUAL-TIME SOLUTION AND VARIOUS ARRIVAL ($\delta_{\mathbb{C}}$) IN NOV - DEC, 1964

MTP-AERO-62-73

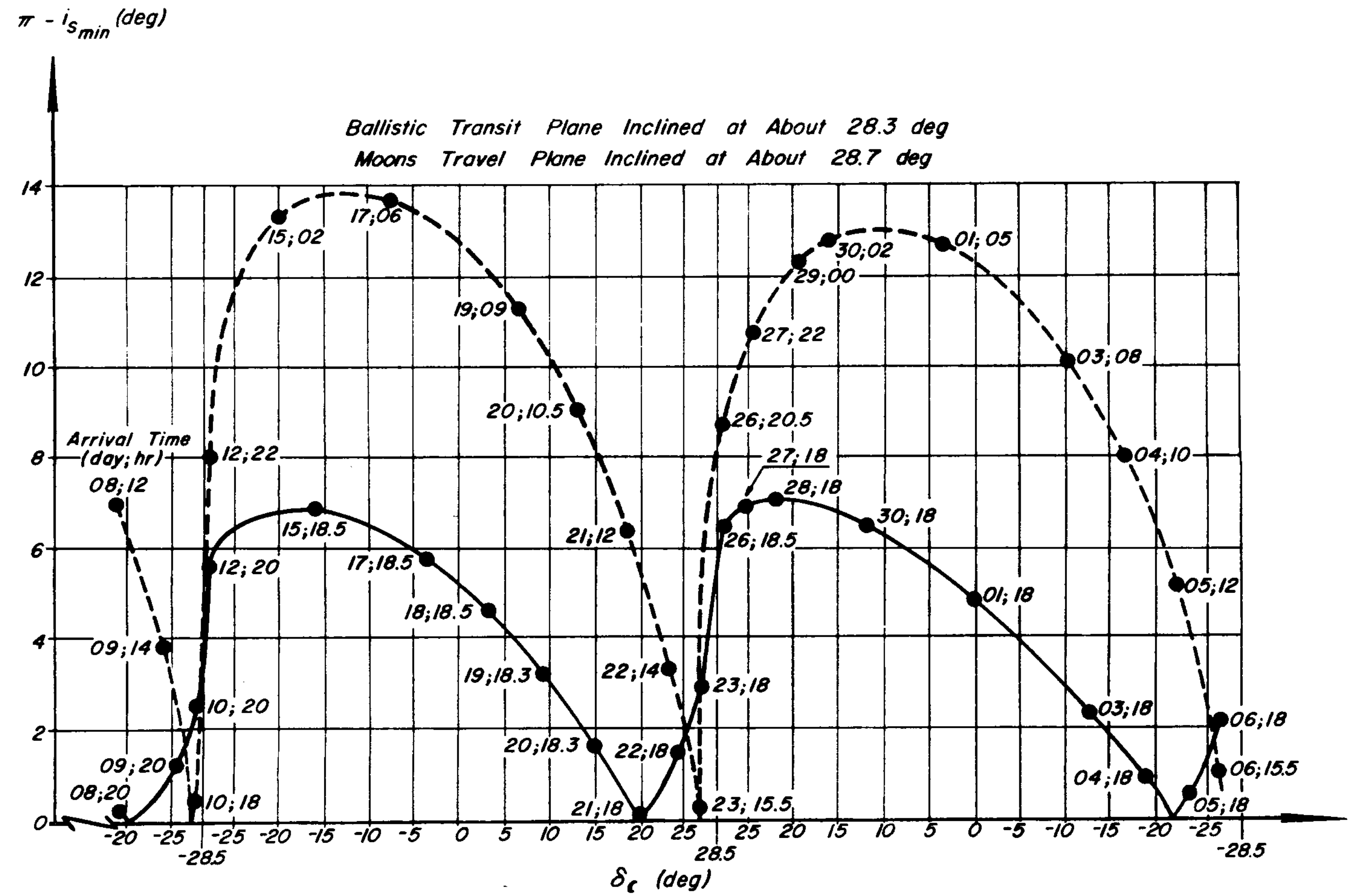


FIG. 6. MINIMUM ATTAINABLE (i_S) FOR THE DUAL-TIME SOLUTION AND VARIOUS ARRIVAL (δ_{ζ}) IN MAR-APR, 1969.

MTP-AERO-62-73

TABLE 7

$\Omega_M \approx -275.5$

$i_{po} \approx 24.4°$
$i_M \approx 24.5°$

ID: NEAR CO-PLANAR SOLUTION
TIME OF SURVEY: Nov-Dec 1964

ARRIVAL CONDITIONS										DEPARTURE CONDITIONS				
LUNAR POSITION (EQ. T. D)			SELENOCENTRIC							GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD. HR. MM)	h_s (km)	ϕ'_s (deg)	σ_s (deg)	i_s (deg)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\oplus N}$ (deg)	$\alpha_{\oplus N}$ (deg)	α (deg)	Σ (deg)
294.65	-24.08	404,536	10 04 44	185.07	0.81	270.76	1.12	2573.32	190.19	19.59	0.5	13.13	141.56	104.90
307.46	-22.52	402,477	11 04 42	185.17	-0.11	269.75	0.27	2574.43	188.84	16.11	0.2	12.82	153.37	108.63
331.63	-16.67	395,144	13 03 07	191.36	-1.99	267.99	2.83	2567.96	185.61	7.71	0.1	12.66	175.34	113.28
355.94	-7.45	383,985	15 03 06	208.97	-3.49	266.40	5.01	2547.67	181.86	-2.47	0	12.60	198.03	114.35
20.77	3.73	371,933	17 03 04	180.53	-4.57	265.47	6.43	2545.55	178.00	-12.86	-0.1	12.54	222.67	110.98
33.93	9.46	366,766	18 03 04	185.50	-4.97	265.41	6.77	2534.13	176.72	-17.49	-0.1	12.50	236.36	107.37
78.46	22.68	359,762	21 03 02	185.69	-4.06	266.07	5.65	2511.61	176.04	-24.43	-0.6	11.97	283.41	89.40
94.63	24.39	360,820	22 02 51	184.56	-3.40	266.72	4.72	2507.35	177.08	-23.04	-3.5	9.13	299.71	81.64
111.13	24.37	363,433	23 03 09	174.80	-2.01	267.97	2.86	2509.34	178.54	-21.07	1.4	13.95	315.99	77.32
126.86	22.67	367,176	24 03 05	184.51	-0.81	269.11	1.21	2503.24	180.63	-16.96	0.5	13.06	330.93	72.13
141.72	19.57	371,680	25 03 05	184.43	0.36	270.47	0.59	2504.46	182.85	-12.02	0.2	12.84	344.93	68.54
155.55	15.44	376,535	26 03 04	191.38	1.66	271.67	2.36	2504.50	185.28	-6.58	0.2	12.75	358.07	66.39
168.47	10.62	381,413	27 03 03	182.26	2.92	272.65	3.95	2514.72	187.44	-0.96	0.1	12.71	10.59	65.56
180.67	5.43	386,061	28 03 03	167.67	3.82	273.58	5.23	2529.29	189.32	4.55	0.1	12.68	22.76	65.94
203.90	-5.11	394,113	30 03 01	189.23	4.67	274.79	6.69	2533.73	192.49	14.42	0	12.61	47.05	70.04
215.41	-10.05	397,414	01 03 00	181.23	4.91	274.79	6.86	2545.64	193.30	18.38	0	12.56	59.52	73.59
239.07	-18.36	402,542	03 02 58	184.13	4.33	274.31	6.11	2557.87	193.87	23.49	-0.2	12.36	85.41	83.07
264.09	-23.48	405,619	05 02 53	190.43	2.82	273.17	4.24	2565.10	193.13	24.09	-1.0	11.61	111.80	94.20
302.92	-23.28	405,188	08 02 58	188.39	0.07	270.09	0.12	2574.44	190.00	17.56	0.9	13.49	149.36	107.28
327.02	-18.16	400,539	10 01 22	184.60	-1.66	268.12	2.51	2575.51	187.05	9.50	0.4	12.99	171.39	112.64

TABLE 8

$\Omega_M \approx -275.5$

$i_{po} \approx 24.4°$
$i_M \approx 24.6°$

ID: OUT-OF-PLANE SOLUTION
TIME OF SURVEY: Nov-Dec 1964

ARRIVAL CONDITIONS											DEPARTURE CONDITIONS				
LUNAR POSITION (EQ, T, D)			SELENOCENTRIC								GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD, HR, MM)	h_s (km)	ϕ'_s (deg)	σ_s (deg)	i_s (deg)	V_s (m/s)	λ_s (deg)		ϕ' (deg)	$\Delta\alpha_{\oplus N}$ (deg)	$\alpha_{\oplus N}$ (deg)	α (deg)	Σ (deg)
295.59	-24.00	404,427	10 06 29	192.88	-0.49	269.62	0.62	2571.06	189.95		23.94	28.5	41.08	143.26	95.01
309.31	-22.20	402,075	11 08 12	185.06	-2.54	267.55	3.53	2580.24	188.19		24.42	56.1	68.67	156.44	89.07
335.89	-15.27	393,406	13 11 29	198.32	-6.10	264.20	8.41	2580.69	184.43		21.26	109.1	121.72	180.57	77.64
1.82	-4.87	381,021	15 14 41	185.79	-8.31	261.67	11.74	2583.41	180.44		12.92	161.0	173.60	203.90	69.05
28.90	7.33	368,590	17 18 03	183.94	-9.51	260.66	13.30	2565.99	177.57		0.82	215.6	228.15	229.96	65.55
43.63	13.28	363,837	18 19 54	183.97	-9.25	260.81	13.01	2551.30	176.73		-5.82	245.4	258.02	245.08	66.20
94.42	24.38	360,796	22 02 32	180.31	-3.21	266.02	5.11	2509.78	177.04		-22.36	-8.4	4.22	299.37	79.88
111.99	24.32	363,608	23 04 26	184.90	-0.88	269.08	1.28	2505.08	178.56		-23.88	21.9	34.45	317.38	84.69
129.09	22.29	367,798	24 06 36	184.13	2.00	271.99	2.82	2510.59	180.60		-24.36	56.6	69.15	334.38	91.97
144.97	18.70	372,772	25 08 34	272.05	18.14	274.42	6.24	2470.63	183.86		-22.98	88.1	100.68	349.63	98.54
159.57	14.03	378,031	26 10 22	183.61	6.20	276.40	8.90	2531.54	185.57		-20.15	117.0	129.58	3.40	104.14
173.10	8.71	383,188	27 12 01	183.16	7.75	277.68	10.90	2542.60	188.01		-16.23	143.8	156.40	16.21	108.54
185.87	3.09	387,988	28 13 35	184.77	8.72	278.62	12.24	2551.23	190.16		-11.57	169.2	181.79	28.53	111.70
210.41	-7.95	396,045	30 16 36	183.55	9.53	278.95	13.05	2564.94	193.23		-1.09	218.2	230.84	53.24	114.44
248.52	-20.77	403,981	03 21 21	185.01	6.46	276.47	9.13	2569.23	194.08		14.15	295.1	307.72	94.04	110.15
304.41	-23.07	405,015	08 05 46	184.53	-1.78	268.19	2.54	2580.39	189.45		24.39	45.7	58.32	151.95	91.50

TABLE 9

$\Omega_M \approx -359.4$

$i_{po} \approx 28.3$
$i_M \approx 28.7$

NEAR COPLANAR SOLUTION
TIME OF SURVEY: March - April 1969

ARRIVAL CONDITIONS										DEPARTURE CONDITIONS				
LUNAR POSITION (EQ, T, D)			SELENOCENTRIC							GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD_γ, HR, MM)	h_s (km)	ϕ'_s (deg)	σ_s (deg)	i_s (m/s)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\bullet N}$ (deg)	$\alpha_{\bullet N}$ (deg)	α (deg)	Σ (deg)
223.43	-20.52	373,915	08 19 52	186.64	0.16	270.18	0.23	2531.69	180.36	26.66	-0.7	359.61	68.59	80.22
237.81	-24.79	372,133	09 19 50	170.57	-0.80	269.00	1.28	2535.50	179.95	28.18	-1.4	358.94	84.04	87.68
253.06	-27.62	370,776	10 19 41	185.34	-1.85	268.15	2.62	2524.01	180.14	27.65	-3.6	356.71	99.71	96.12
285.46	-27.88	369,413	12 20 07	158.21	-4.30	266.16	5.76	2532.95	180.79	23.22	3.5	3.85	130.93	106.59
328.68	-16.05	372,004	15 18 24	175.35	-4.87	265.19	6.85	2521.09	183.84	5.78	0.7	1.01	170.17	117.75
353.91	-3.51	377,745	17 18 22	185.85	-3.89	265.84	5.70	2517.65	186.59	-7.62	0.3	0.58	194.96	117.34
5.80	2.99	381,691	18 18 21	192.26	-3.15	266.67	4.57	2516.96	188.08	-13.79	0.1	0.41	207.52	114.96
17.56	9.21	386,083	19 18 19	187.90	-2.21	267.73	3.17	2523.18	189.44	-19.17	-0.1	0.21	220.45	111.21
29.42	14.91	390,621	20 18 18	187.74	-1.02	268.77	1.59	2528.55	190.74	-23.49	-0.3	359.97	233.85	106.21
41.57	19.86	394,966	21 18 16	183.31	-0.09	269.98	0.07	2537.32	191.82	-26.51	-0.7	359.63	247.66	100.21
54.12	23.85	398,780	22 18 13	190.75	1.11	271.18	1.61	2540.80	192.77	-28.07	-1.2	359.10	261.67	93.51
67.08	26.72	401,757	23 18 08	189.82	2.13	272.13	3.02	2548.92	193.31	-28.06	-2.4	357.92	275.55	83.40
107.46	27.64	403,683	26 18 27	180.45	4.42	274.73	6.47	2571.94	192.43	-22.05	3.3	3.64	314.78	71.84
120.48	25.36	401,773	27 18 20	183.71	5.02	274.70	6.88	2572.68	191.43	-17.47	1.7	2.11	326.31	67.40
133.10	21.92	398,733	28 18 17	188.60	5.01	274.88	6.99	2570.27	190.07	-12.38	1.2	1.49	337.43	64.36
157.14	12.18	390,245	30 18 13	156.30	4.30	274.77	6.42	2580.42	186.25	-0.90	0.6	0.87	359.19	61.71
180.49	-0.08	380,769	01 18 10	176.06	3.65	273.27	4.90	2557.20	182.85	11.18	0.2	0.51	22.04	63.83
205.05	-12.89	373,048	03 18 07	172.65	1.68	271.70	2.39	2544.17	180.05	21.80	-0.2	0.09	48.12	71.53
218.43	-18.66	370,466	04 18 06	178.35	0.75	270.55	0.93	2534.37	179.33	25.61	-0.5	359.79	62.82	77.60
232.81	-23.47	368,866	05 18 04	185.17	-0.44	269.53	0.64	2524.88	179.11	27.85	-1.0	359.27	78.49	84.92
248.14	-26.88	368,216	06 17 59	185.80	-1.53	268.53	2.13	2519.77	179.33	28.11	-2.3	357.97	94.61	93.14
324.17	-17.89	374,709	11 16 37	127.96	-4.53	264.85	6.84	2546.16	184.57	7.87	0.7	1.03	166.15	117.27

TABLE 10

$\Omega_M \approx -359.4$

$i_{po} \approx 28.3$
$i_M \approx 28.7$

OUT-OF-PLANE SOLUTION
TIME OF SURVEY: March-April 1969

ARRIVAL CONDITIONS										DEPARTURE CONDITIONS				
LUNAR POSITION (EQ, T, D)			SELENOCENTRIC							GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD, HR, MM)	h_s (km)	ϕ'_s (deg)	σ_s (deg)	i_s (m/s)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\bullet N}$ (deg)	$\alpha_{\bullet N}$ (deg)	α (deg)	Σ (deg)
219.04	-18.91	374,575	08 12 13	181.78	5.03	274.84	6.98	2558.46	181.31	10.50	261.3	261.59	61.44	116.42
234.32	-23.90	372,516	09 14 10	184.41	2.98	272.46	3.87	2541.48	180.70	17.11	292.8	293.08	78.19	112.87
252.00	-27.48	370,854	10 18 04	153.88	-0.40	269.71	0.50	2543.39	180.02	23.33	330.6	330.93	97.61	106.44
286.71	-27.73	369,403	12 22 00	185.28	-5.76	264.20	8.17	2521.86	181.09	27.94	33.5	33.80	133.21	94.44
319.43	-19.74	370,815	15 02 12	182.52	-9.56	260.77	13.26	2541.18	183.73	25.58	100.5	100.84	163.72	77.53
347.48	-6.95	375,918	17 05 40	179.50	-10.01	260.41	13.82	2557.52	186.95	16.03	156.8	157.10	189.36	66.37
12.90	6.80	384,310	19 08 50	184.73	-7.91	262.03	11.21	2558.45	189.93	3.31	208.0	208.35	214.51	61.88
25.49	13.11	389,131	20 10 24	185.29	-6.38	263.58	9.04	2557.15	191.17	-3.22	233.5	233.85	227.85	61.87
38.37	18.66	393,872	21 12 01	184.84	-4.59	265.53	6.40	2555.80	192.19	-9.49	259.7	260.05	241.96	63.22
51.73	23.18	398,119	22 13 43	184.10	-2.53	267.78	3.37	2555.14	192.94	-15.28	287.1	287.40	256.88	65.91
65.65	26.47	401,481	23 15 31	184.96	0.20	269.87	0.24	2555.36	193.38	-20.48	316.1	316.44	272.46	70.07
108.61	27.49	403,566	26 20 32	186.23	6.06	276.28	8.72	2572.53	192.40	-27.88	36.5	36.78	317.13	85.12
122.62	24.86	401,337	27 22 21	184.15	7.77	277.63	10.87	2582.56	191.26	-28.15	65.8	66.06	330.25	92.74
136.07	20.93	397,857	29 00 02	183.13	8.67	278.66	12.23	2590.73	189.77	-26.63	93.0	93.36	342.17	99.86
148.98	15.92	393,434	30 01 39	185.15	9.08	279.23	12.92	2594.64	188.08	-23.50	119.1	119.41	353.31	106.21
173.93	3.51	383,354	01 04 45	182.31	9.60	278.48	12.78	2594.67	184.64	-13.14	167.4	169.72	15.42	115.29
199.63	-10.25	374,427	03 07 57	161.99	7.25	277.27	10.25	2586.94	181.42	0.72	221.6	221.91	40.57	118.29
213.65	-16.74	371,257	04 09 44	320.90	5.29	276.13	8.09	2493.98	181.80	8.03	250.3	250.58	55.38	117.22
228.88	-22.31	369,197	05 11 41	182.05	3.71	273.68	5.22	2544.23	179.87	15.03	281.6	281.91	71.99	114.25
246.53	-26.61	368,242	06 15 31	171.50	0.64	270.90	1.11	2532.81	179.49	21.60	318.6	318.90	91.48	108.70
314.54	-21.42	373,119	10 23 48	184.39	-8.98	260.92	12.74	2534.94	184.57	26.56	90.8	91.12	159.52	79.96

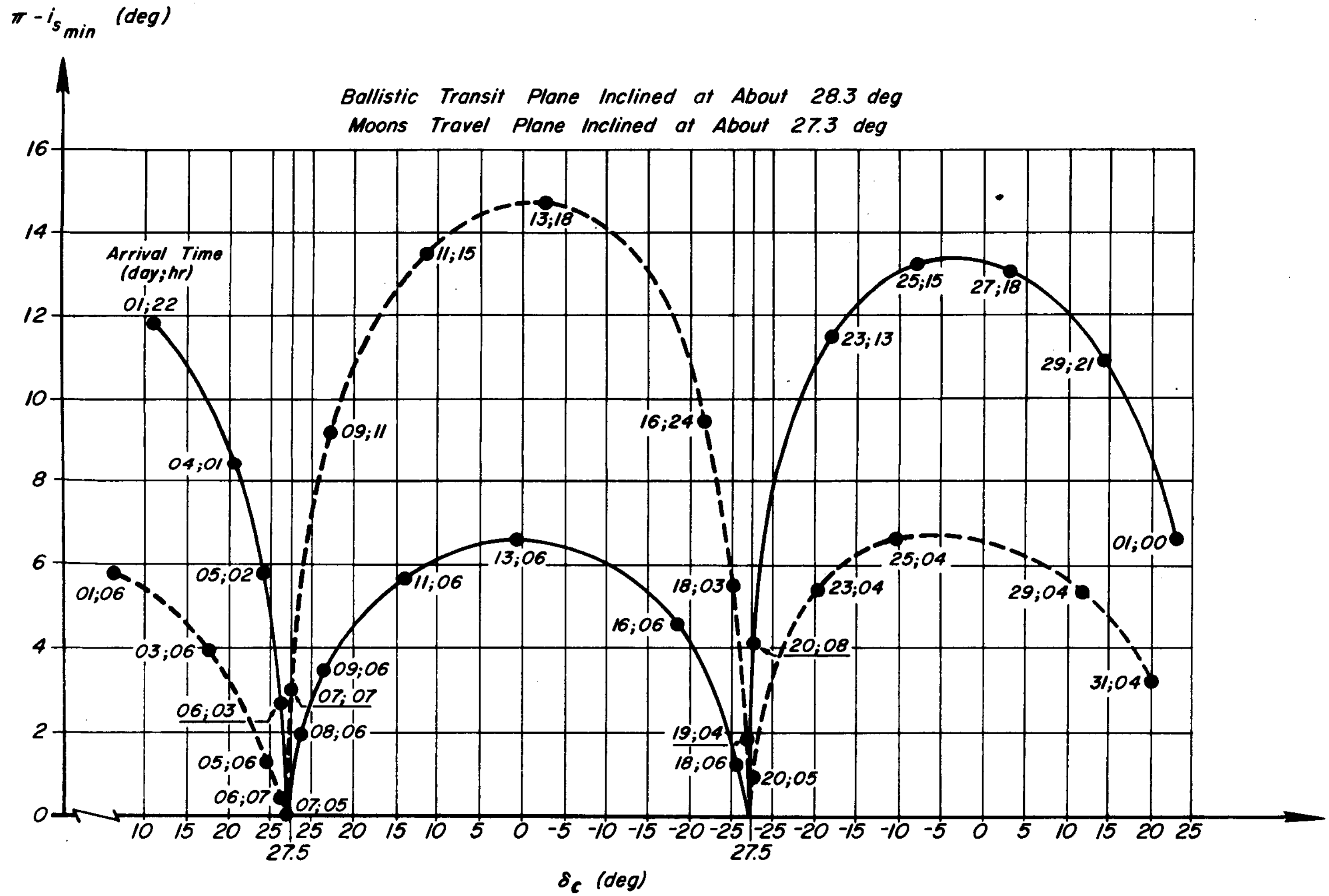


FIG. 7. MINIMUM ATTAINABLE (i_s)

FOR THE DUAL-TIME SOLUTION AND VARIOUS ARRIVAL (δ_c) IN OCT, 1966

MTP-AERO-62-73

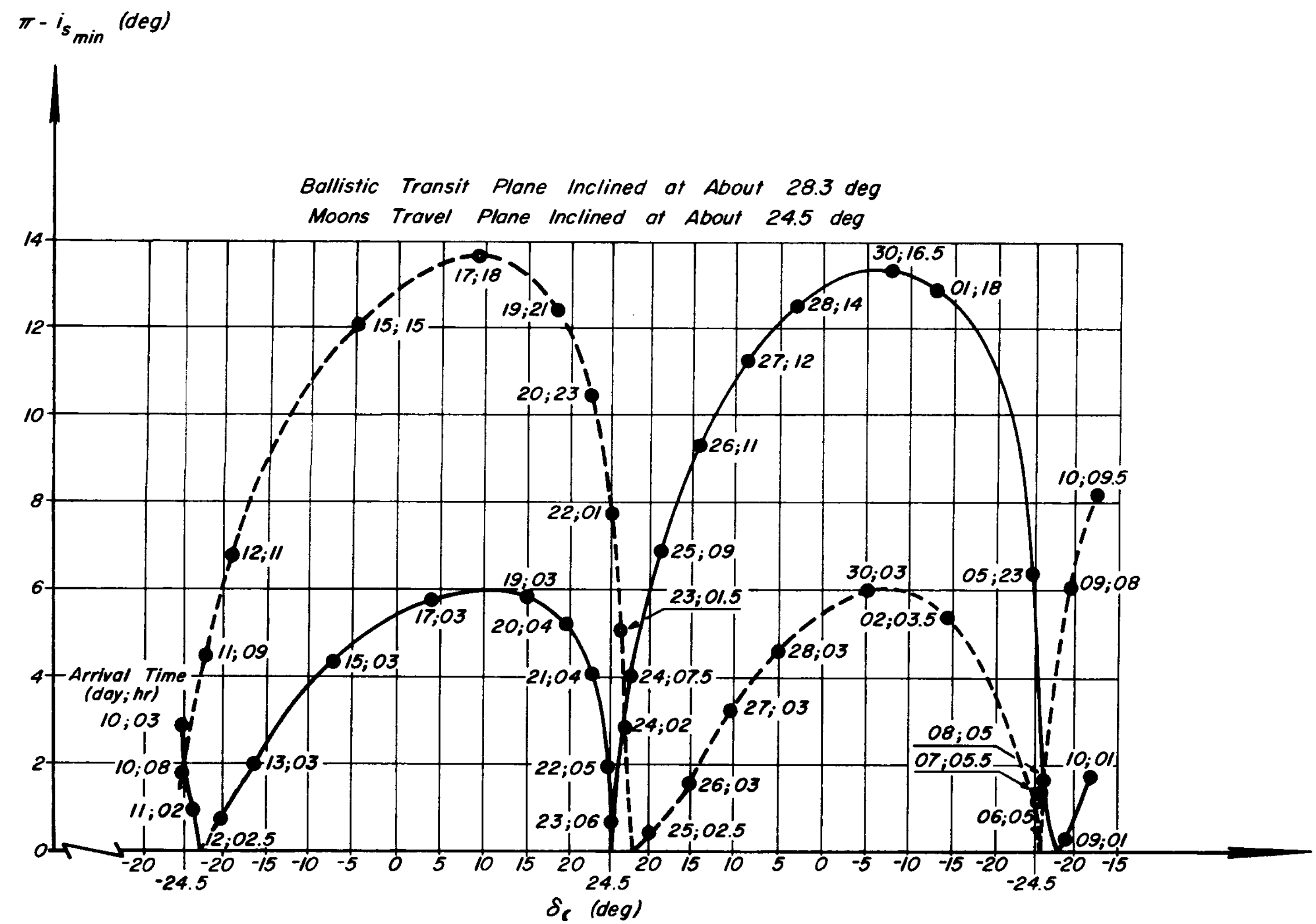


FIG. 8. MINIMUM ATTAINABLE (i_s) MTP-AERO-62-73

FOR THE DUAL-TIME SOLUTION AND VARIOUS ARRIVAL $(\delta_\mathfrak{c})$ IN NOV-DEC, 1964.

TABLE 11

$\Omega_M \approx -312.5$ $i_{po} \approx 28.3$ $i_M \approx 27.3$

LOW-HIGH I
TIME OF SURVEY: October 1966

ARRIVAL CONDITIONS										DEPARTURE CONDITIONS				
LUNAR POSITION (EQ, T, D)			SELENOCENTRIC							GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD, HR, MM)	h_s (km)	ϕ'_s (deg)	σ_s (deg)	i_s (deg)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\oplus N}$ (deg)	$\alpha_{\oplus N}$ (deg)	α (deg)	Σ (deg)
30.69	11.13	401,455	01 21 38	183.61	-8.10	261.44	11.77	2603.55	189.19	-0.56	226.1	234.40	233.35	61.71
55.92	20.86	395,028	04 00 40	185.90	-6.10	264.22	8.36	2583.78	185.88	-12.11	275.2	283.53	260.05	64.24
69.97	24.42	390,785	05 02 19	184.95	-4.06	265.97	5.72	2572.18	183.93	-17.14	301.8	310.08	275.10	67.16
84.97	26.65	385,929	06 03 56	181.45	-1.83	268.04	2.68	2562.60	181.90	-20.88	327.7	336.03	290.86	70.49
100.46	27.26	380,690	07 05 06	182.43	0.03	270.04	0.05	2553.18	180.03	-21.90	346.4	354.65	306.30	71.65
115.87	26.18	375,378	08 05 33	181.74	1.45	271.34	1.97	2546.00	178.42	-19.56	353.7	2.03	320.69	69.16
131.04	23.44	370,234	09 05 43	182.74	2.37	272.48	3.43	2538.05	177.11	-15.22	356.5	4.76	334.40	65.87
160.04	13.71	361,913	11 05 50	184.20	4.08	273.87	5.62	2522.99	175.60	-3.31	358.8	7.05	0.89	61.88
187.36	0.47	358,901	13 05 55	187.61	4.60	274.64	6.53	2509.40	176.21	10.17	0.1	8.36	27.83	63.45
228.59	-18.48	367,414	16 06 03	187.54	3.27	273.30	4.65	2501.28	181.33	25.48	2.3	10.56	72.91	77.30
257.92	-25.84	379,090	18 06 18	186.04	0.78	271.00	1.26	2507.50	186.28	28.27	6.4	14.68	105.00	90.15
288.05	-26.99	391,416	20 07 53	189.11	-2.91	267.07	4.13	2523.98	190.82	28.14	31.8	40.11	135.99	92.78
329.22	-18.04	403,683	23 12 30	181.77	-8.26	261.97	11.50	2577.19	194.20	25.11	106.2	114.50	175.12	76.56
352.76	-7.88	405,549	25 15 18	184.86	-9.32	260.55	13.25	2599.58	193.76	17.71	151.7	160.00	196.39	67.57
15.20	3.56	403,240	27 17 58	180.61	-9.20	260.68	13.06	2608.97	191.66	7.27	195.6	203.93	217.63	62.57
38.78	14.70	398,222	29 20 49	180.55	-7.76	262.20	10.98	2598.92	188.62	-4.60	242.0	250.27	241.68	62.05
65.52	23.51	391,665	01 00 02	184.66	-4.25	264.99	6.56	2574.27	185.06	-15.82	293.8	302.11	270.33	66.24

TABLE 12

$\Omega_M \approx -312.5$ $\quad$ $i_{po} \approx 28.3$ $\quad$ $i_M \approx 27.3$

HIGH-LOW, II
TIME OF SURVEY: October 1966

ARRIVAL CONDITIONS											DEPARTURE CONDITIONS				
LUNAR POSITION (EQ, T, D)			SELENOCENTRIC								GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD, HR, MM)			h_s (km)	ϕ'_s (deg)	σ_s (deg)	h_s (deg)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\bullet N}$ (deg)	$\alpha_{\bullet N}$ (deg)	α (deg)	Σ (deg)
23.54	7.75	402,886	01	06	05	185.49	-3.95	265.81	5.75	2576.28	189.86	-18.28	0.8	9.12	226.97	111.98
46.39	17.65	397,674	03	06	08	181.84	-2.63	267.09	3.93	2573.68	186.61	-25.28	2.2	10.45	251.86	103.10
72.24	24.86	390,069	05	06	18	185.26	-0.97	269.16	1.28	2563.19	183.18	-28.21	5.2	13.48	279.41	91.93
86.57	26.79	385,397	06	06	35	182.92	0.32	270.32	0.45	2558.77	181.39	-28.14	9.8	18.11	293.89	87.26
101.92	27.23	380,190	07	07	25	185.21	1.90	272.15	2.87	2552.10	179.62	-28.07	23.3	31.63	308.93	86.55
134.23	22.66	369,190	09	10	51	185.28	6.52	276.46	9.17	2550.48	176.67	-27.14	78.3	86.63	339.03	98.24
165.07	11.49	360,893	11	14	32	184.28	9.46	279.56	13.42	2555.45	176.00	-19.32	137.5	145.80	6.44	111.08
194.15	-3.03	359,253	13	18	02	196.40	10.45	280.36	14.67	2542.66	178.15	-6.08	194.4	202.68	34.09	117.69
239.05	-21.81	371,341	16	23	30	185.40	6.65	276.78	9.48	2518.37	184.08	14.28	282.2	290.47	82.25	114.68
255.87	-25.53	378,227	18	02	58	184.18	4.00	273.93	5.61	2513.50	186.52	19.33	313.3	321.59	100.90	111.05
271.58	-27.17	384,808	19	04	30	186.43	1.34	271.29	1.86	2514.37	188.80	21.88	337.8	346.10	117.79	108.37
286.52	-27.09	390,827	20	05	18	185.18	-0.72	269.40	0.94	2522.60	190.87	21.18	350.6	358.92	132.85	109.19
325.14	-19.47	402,901	23	04	11	183.52	-3.88	266.28	5.38	2552.61	194.40	9.12	357.9	6.24	168.88	116.90
347.80	-10.26	405,546	25	04	15	203.42	-4.54	265.23	6.58	2558.00	194.38	-1.46	359.2	7.54	190.26	119.57
30.87	11.22	400,063	29	04	18	183.59	-3.78	266.23	5.34	2574.93	189.31	-20.94	1.2	9.46	234.80	109.46
54.81	20.57	394,312	31	04	22	184.94	-2.32	267.82	3.18	2567.71	185.95	-26.81	2.7	10.97	260.92	99.34

TABLE 13

$\Omega_M \approx -275.5°$ $i_{po} \approx 28.3°$ $i_M \approx 24.6°$

ID: LOW-HIGH, I
TIME OF SURVEY: Nov-Dec 1964

LUNAR POSITION (EQ, T, D)			ARRIVAL CONDITIONS — SELENOCENTRIC							DEPARTURE CONDITIONS — GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD, HR, MM)	h_s (km)	ϕ'_s (deg)	σ_s (deg)	i_s (deg)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\bullet N}$ (deg)	$\alpha_{\bullet N}$ (deg)	α (deg)	Σ (deg)
293.10	-24.20	404,703	10 01 52	185.33	2.01	271.97	2.81	2574.12	190.51	15.88	337.9	350.52	138.60	113.72
306.18	-22.72	402,738	11 02 18	187.78	0.67	270.72	0.98	2573.70	189.13	13.63	345.1	357.72	150.95	115.03
318.96	-20.20	399,548	12 02 35	201.21	-0.46	269.56	0.64	2566.11	187.62	10.24	349.8	2.36	162.73	116.51
331.44	-16.73	395,217	13 02 46	205.31	-1.43	268.50	2.07	2561.26	185.82	6.07	353.0	5.59	174.19	117.69
355.90	-7.47	384,003	15 03 02	218.02	-3.10	266.88	4.40	2543.38	181.96	-3.73	357.4	10.18	197.14	119.37
20.86	3.78	371,892	17 03 15	206.63	-4.14	265.94	5.80	2532.38	178.21	-14.14	1.8	14.08	221.99	114.76
48.18	14.92	362,741	19 03 33	218.66	-4.26	265.90	5.91	2508.96	176.09	-22.93	6.4	18.98	250.83	107.02
63.23	19.49	360,365	20 03 47	246.23	-3.66	266.17	5.30	2487.66	176.07	-25.83	10.2	22.82	266.98	101.92
79.25	22.80	359,775	21 04 11	196.48	-2.96	267.16	4.10	2506.89	176.00	-27.43	16.5	29.10	283.95	97.11
96.03	24.46	360,984	22 04 53	171.35	-1.43	268.47	2.10	2516.51	176.77	-27.96	27.8	40.42	301.29	94.31
113.09	24.24	363,837	23 06 04	193.06	0.60	270.47	0.76	2505.68	178.58	-27.83	46.7	59.32	318.41	95.36
129.73	22.18	367,979	24 07 37	194.02	2.85	272.77	3.97	2510.88	180.71	-26.92	71.2	83.83	334.60	98.98
145.36	18.59	372,905	25 09 14	182.44	4.84	274.96	6.93	2526.26	183.05	-24.87	97.3	109.88	349.39	103.91
159.81	13.94	378,121	26 10 48	181.84	6.55	276.71	9.37	2537.27	185.57	-21.68	122.7	135.28	2.91	108.62
173.24	8.65	383,242	27 12 18	182.49	8.03	277.91	11.25	2547.40	188.00	-17.58	146.9	159.50	15.57	112.53
185.94	3.06	388,013	28 13 44	182.04	8.98	278.80	12.55	2556.89	190.12	-12.84	170.1	182.71	27.77	115.43
210.36	-7.93	396,029	30 16 30	186.09	9.47	279.46	13.36	2567.69	193.17	-2.48	215.1	227.66	52.28	118.20
222.62	-12.89	399,213	01 17 52	183.29	9.44	278.84	12.91	2572.38	194.00	2.66	237.5	250.06	65.12	119.49
274.96	-24.43	406,198	05 23 04	217.82	3.67	274.21	5.59	2557.93	192.98	16.49	321.5	334.09	120.71	113.31
301.56	-23.45	405,335	08 00 24	195.58	0.98	271.13	1.50	2571.42	190.35	14.06	343.2	355.83	146.75	114.47
314.37	-21.31	403,489	09 00 43	195.78	-0.12	269.83	0.21	2571.47	188.88	11.62	348.6	1.16	158.70	115.98
326.80	-18.23	400,602	10 00 55	203.15	-1.41	268.92	1.77	2566.52	187.33	7.72	352.1	4.74	170.12	117.31

TABLE 14

$\Omega_M \approx -275.5°$

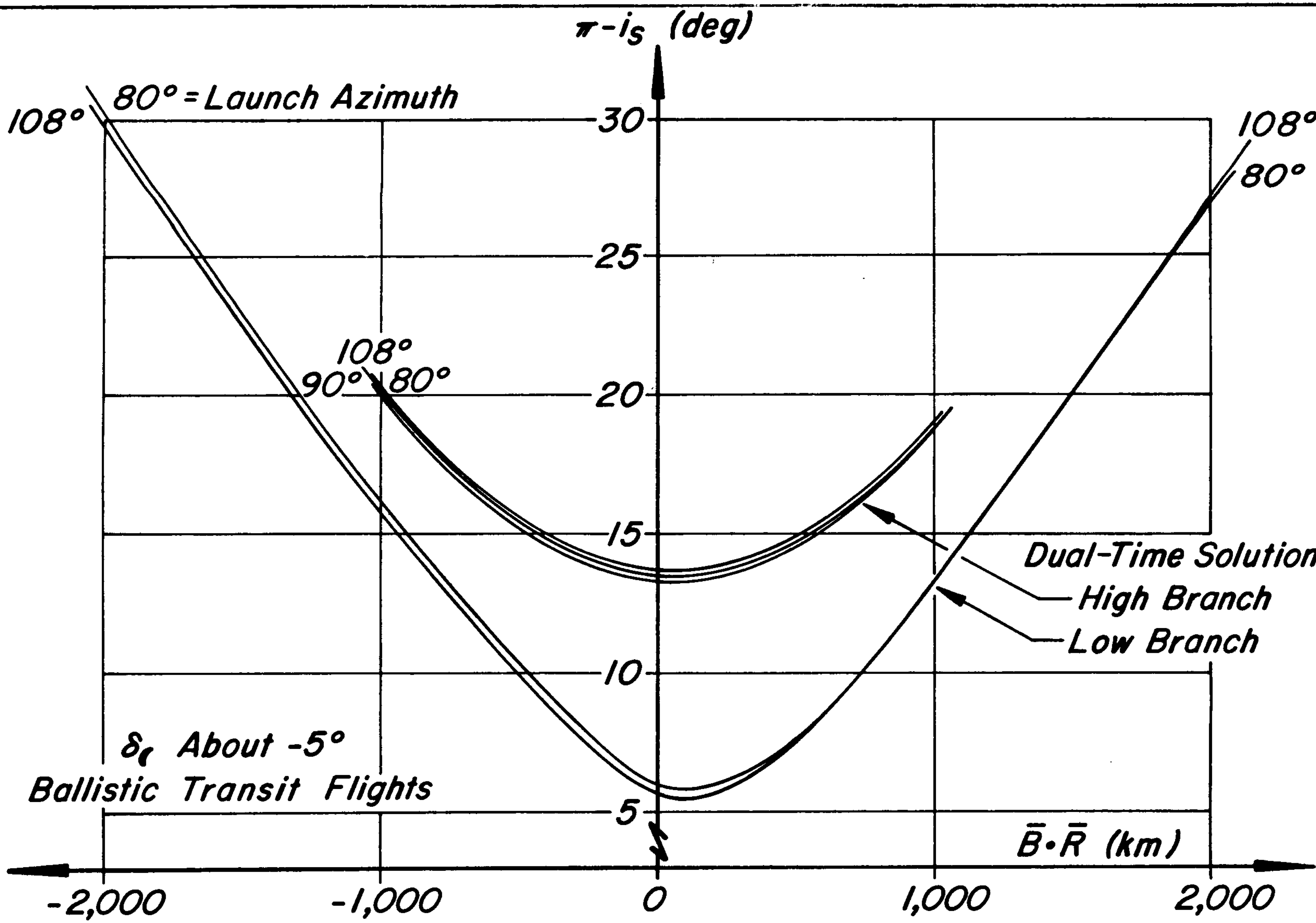
$i_{po} \approx 28.3°$
$i_M \approx 24.6°$

ID: HIGH-LOW, II
TIME OF SURVEY: Nov-Dec 1964

ARRIVAL CONDITIONS										DEPARTURE CONDITIONS				
LUNAR POSITION (EQ, T, D)			SELENOCENTRIC							GEOCENTRIC				
α_M (deg)	δ_M (deg)	ρ_M (km)	Time (DD, HR, MM)	h_s (km)	ϕ_s' (deg)	σ_s (deg)	i_s (deg)	V_s (m/s)	λ_s (deg)	ϕ' (deg)	$\Delta\alpha_{\oplus N}$ (deg)	$\alpha_{\oplus N}$ (deg)	α (deg)	Σ (deg)
296.37	-23.93	404,331	10 07 57	205.45	-1.51	268.59	2.07	2568.79	189.75	27.98	50.5	63.10	144.26	85.83
309.84	-22.11	401,957	11 09 12	183.00	-3.20	266.87	4.48	2585.61	187.94	27.30	70.7	83.28	156.93	82.34
323.10	-19.16	398,240	12 10 34	222.96	-4.77	265.18	6.78	2570.14	186.46	25.73	92.8	105.37	169.02	77.86
1.91	-4.83	380,976	15 14 52	183.07	-8.47	261.41	12.04	2589.05	180.34	14.41	162.6	175.22	203.72	65.38
28.84	7.31	368,613	17 17 56	181.57	-9.72	260.37	13.65	2571.92	177.55	2.35	212.6	225.16	229.54	61.79
59.15	18.38	360,825	19 21 21	183.58	-8.95	261.28	12.47	2540.31	176.47	-10.11	267.7	280.26	260.91	63.43
75.86	22.24	359,747	20 23 07	189.58	-7.44	262.66	10.44	2521.45	176.69	-14.89	295.7	308.26	278.64	65.67
93.12	24.31	360,654	22 00 38	187.28	-5.38	264.45	7.73	2510.99	177.42	-17.50	321.0	332.55	296.68	67.42
110.13	24.42	363,235	23 01 40	182.14	-3.43	266.32	5.04	2507.48	178.78	-17.23	336.4	349.03	313.83	67.22
126.31	22.75	367,026	24 02 14	188.57	-1.84	268.13	2.63	2502.01	180.76	-14.44	345.6	358.17	329.57	65.41
141.40	19.65	371,574	25 02 33	177.79	-0.39	269.75	0.46	2508.60	182.87	-10.10	350.6	3.31	344.00	63.43
155.38	15.50	376,472	26 02 45	187.53	1.09	271.07	1.52	2506.86	185.27	-4.93	354.0	6.62	357.40	62.10
168.39	10.66	381,382	27 02 54	199.07	2.26	272.30	3.22	2506.27	187.61	0.57	356.4	9.04	10.11	61.70
180.66	5.44	386,055	28 03 01	191.53	3.24	273.23	4.58	2511.98	189.54	6.06	358.4	11.03	22.41	62.30
204.00	-5.15	394,143	30 03 13	54.46	4.27	274.31	6.07	2607.84	191.16	16.03	2.0	14.62	46.88	66.37
227.32	-14.61	400,273	02 03 27	224.96	4.18	274.20	5.93	2531.08	194.09	23.42	6.2	18.77	72.40	73.68
278.07	-24.56	406,274	06 04 50	215.49	0.69	270.70	0.98	2558.61	192.18	28.17	29.0	41.59	126.32	87.50
291.55	-24.37	406,083	07 05 44	194.53	-0.87	269.12	1.23	2574.17	190.76	28.10	43.8	56.38	139.69	86.83
318.27	-20.45	402,706	09 08 15	184.48	-4.18	265.68	6.01	2590.00	187.53	26.50	84.3	96.91	164.89	79.77
331.18	-16.91	399,303	10 09 37	182.29	-5.69	264.15	8.16	2595.27	185.73	24.35	106.7	119.26	176.53	75.16

B. THE INFLUENCE OF LAUNCH AZIMUTH VARIATIONS

Consider Figure 9 as basis for drawing the conclusion that launch azimuth variations have a negligible influence upon the minimum attainable inclinations. In a sense this variation had been studied previously under the OUT-OF-PLANE TRANSIT CASES, in which it was found that the day-to-day minima inclinations did not change significantly (less than 1°).



MTP-AERO-62-73

FIG. 9. ARRIVAL-INCLINATION SURVEY FOR FLIGHTS OF 66 HOURS ARRIVING ON NOV 30, 1964 WITH LAUNCH AZIMUTH AS A PARAMETER

APPROVAL MTP-AERO-62-73

EARTH-MOON TRANSIT STUDIES BASED ON EPHEMERIS DATA AND USING BEST AVAILABLE COMPUTER PROGRAM

PART I: PERISELENUM CONDITIONS AS FUNCTION OF INJECTION CONDITIONS

BYRD TUCKER

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be UNCLASSIFIED.

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